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Temperatures, Growth, and Fall of Needles on Engelmann Spruce Infested by Spruce Beetles

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Needle temperatures of Engelmann spruce (*Picea engelmannii* Parry) trees infested by spruce beetles (*Dendroctonus rufipennis* (Kirby)) were occasionally significantly higher than those of noninfested spruce between 12 noon and 3:15 LST. However, the mean needle temperatures of infested and noninfested trees were usually within 1°C of each other. Needle temperatures were significantly higher on the east sides than on the west sides of both infested and noninfested spruce in the morning and higher on the west sides in the afternoon. Infested trees produced new needles the summer following beetle attack. Most needles were stripped from the infested trees during thunderstorms two summers after beetle attack. The effects of needle temperatures, new growth, and foliage discoloration on the remote sensing of infested trees are briefly discussed.

Keywords: *Dendroctonus rufipennis*, *Picea engelmannii*, spruce, temperatures.

Aerial detection of spruce trees (*Picea engelmannii* Parry) infected by spruce beetles (*Dendroctonus rufipennis* (Kirby)) is difficult because few needles discolor during the summer of beetle attack. Visual evidence of infested trees is limited to sawdust in the bark and around the bases of the trees—characteristics certainly invisible from the air. Needles usually turn a greenish yellow and fall about a year after attack, although some trees may remain green until the fall of the second year (Massey and Wygant 1954). When a large group of infested trees has discolored or lost a substantial portion of their needles so that they appear like skeletons, they are more easily detected by aerial observers. Scattered individual trees may remain undetected, however, because these foliar changes are subtle.

When Heller et al. (1968) reported that the needles of beetle-infested ponderosa pines (*Pinus ponderosa* Lawson) may be up to 6°C warmer than those of noninfested trees, a previsual solution to the detection problem seemed possible. If similar temperature differences existed between infested and noninfested spruce, thermal imagery might be used to detect the infested spruce prior to their foliar color change and thus give earlier notice of an infestation. Therefore, a study was initiated to determine if the needle temperatures of infested and noninfested spruce differed throughout the period of beetle development in the infested trees (approximately 2 yrs). The crowns of the trees were also observed for the growth, discoloration, and fall of needles to determine other characteristics that might be helpful in detecting infested trees.

Methods

In July 1972 three beetle-infested and three noninfested Engelmann spruce, *Picea engelmannii* Parry, trees were selected for needle temperature measurement on Green Mountain (elevation 3200 m), about 14 km southwest of Encampment, Wyoming. Two subalpine firs, *Abies lasiocarpa* (Hooker) Nuttall, were also monitored. The trees formed a natural circle around a small opening in the forest canopy, which facilitated temperature recordings at a central point.

Two 30-gage copper-constantan thermocouples (accuracy = ± 0.5°C) were inserted in needles in each tree in the upper one-third to one-half of the crown. One thermocouple was placed on the east side of the crown, the other on the west side. Each thermocouple was inserted in an outermost needle on the upper side of a branch. The same needles were used for temper-

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ature measurements until they fell off the branch or it was impossible to retain the wire in the needles.

During 1972 and 1973, the 16 thermocouples (12 from spruce and 4 from fir) were connected to a 16-point strip-chart recorder. When operating, the recorder inscribed a temperature measurement every 30-40 s so that the temperature of a specific needle was recorded about every 8-10 min. In 1974, the thermocouples were connected to a potentiometer without an automatic printout device, and the 16 readings were recorded manually about every hour during periods of observation.

Temperatures were recorded during daylight hours at about 2-week intervals in September and October of 1972; June, July, August, and September of 1973; and June, July, and August of 1974. During recording sessions at least one day of temperatures under relatively cloudless skies was obtained.

Simultaneously with needle temperature recordings, the temperature and humidity of the air at treetop and at 1.5 m aboveground were recorded on charts on hygrothermographs. The hygrothermograph at treetop level was positioned under a plywood platform on the top of a tower, while the hygrothermograph, near ground level, was placed in the shade of several large spruce. A pyranograph at treetop level recorded the intensity of the sun's radiation and, indirectly, the relative cloudiness.

Temperatures were not recorded during nighttime hours. Weber (1969) noted that nocturnal temperature differences were not likely between beetle-infested and noninfested ponderosa pines. Denny et al. (1971) stated that maximum diurnal temperature differences developed between noon and 3 p.m. Since the temperatures of infested and noninfested spruce became nearly identical under general cloud cover, it seemed unlikely that they would become significantly different when the foliage was free from direct solar radiation.

Mean temperatures of infested and noninfested spruce for 8-10 minute periods in 1972 and 1973, and for hourly readings in 1974, were compared by the unpaired "t" test. Differences were considered significant at the .05 level.

Tree Characteristics

Diameters of the infested trees at breast height were 47.5, 43.0, and 40.0 cm, while the noninfested trees were 32.0, 41.0, and 38.5 cm. The trees ranged in height from 22 to 25 m. The trees were attacked in July 1972 by spruce beetles; the density of beetle attacks averaged 4 per 900 cm^2 (30 cm x 30 cm bark samples) at breast height. Attack densities were determined in August 1974 after temperature recordings had ceased. All infested trees had blue stain but the amount varied from streaks to complete coverage of the area exposed under the bark.

Results and Discussion

Needle Temperatures

Mean needle temperatures of infested trees were not consistently warmer than noninfested trees; being warmer only on certain days. Infested trees were 2.5-5°C warmer during specific times on June 21, 22, July 17, 31, and August 2, 1973. Significant temperature differences generally occurred between 12 noon and 3:15 p.m. (1200-1515 hrs) local time (table 1).

Table 1.--Mean temperatures (°C) of three infested and three noninfested Engelmann spruce on a typical August day when significant differences developed[1]

Local sun time	Infested	Non-infested	Difference	"t"
0850	11.6	14.0	-2.4	[2]3.73*
0900	12.3	13.2	-0.9	2.00
0930	13.2	15.2	-2.0	2.41*
0950	15.4	14.7	+0.7	0.83
1000	15.8	14.6	+1.2	1.41
1030	14.9	13.2	+1.7	2.46*
1040	15.1	15.8	-0.7	0.92
1100	14.6	15.4	-0.8	1.62
1110	15.4	14.6	+0.8	1.79
1130	15.8	15.9	-0.1	0.17
1210	19.6	15.0	+4.6	10.25*
1220	20.3	15.4	+4.9	6.93*
1230	17.3	16.0	+1.3	2.45*
1248	19.6	16.1	+3.5	5.43*
1256	21.0	16.8	+4.2	9.74*
1332	20.7	16.6	+4.1	4.31*
1352	19.1	16.7	+2.4	2.38*
1412	19.0	14.7	+4.3	4.14*
1422	14.1	13.9	+0.2	0.50
1512	19.0	14.6	+4.4	6.17*

[1]Temperatures after 1512 LST were not presented because the sky became cloudy. Plus signs in the difference column indicate the infested trees were warmer than the noninfested trees.

[2]Asterisk marks indicate that the given values exceed the 0.05 level value of "t" of 2.23.

Temperatures of noninfested trees were generally higher on June 28 and July 6, 7, and 17, 1973. However, the mean needle temperature of the noninfested trees was rarely 2.5°C warmer than the mean of the infested trees. On other recording days, and the remainder of the specific days, average temperatures were either the same or within 1°C of each other.

The mean temperature differences occasionally changed markedly within a specific hour or between successive recording times. For example, the mean temperature of the infested trees might be 1°C warmer than noninfested trees at a certain time, 4°C warmer 20 min later, and back to 1° warmer in another 20 min. Such changes were probably caused by some of the factors affecting individual needle temperatures.

Individual needle temperatures were affected by wind, shading, and needle location and orientation. Winds estimated to be 8-16 km/h decreased needle temperature 1.5°C; 16-32 km/h winds de-

creased the temperature 3°C. Needle temperatures were influenced by several forms of shading. Cloud cover generally decreased needle temperature. One monitored needle dropped 10°C in 5 min when a cloud obscured the sun and then regained the 10° in 75 s after re-exposure to direct sunlight. Adjacent trees, or branches of the same tree, had a similar shading effect.

Needle temperature was also influenced by the orientation of the needle toward the sun. One needle's temperature varied 2.4° with changing sun angle; its temperature was highest when the flat surface was perpendicular to the direct solar radiation.

Needle temperatures differed significantly between the east and west sides of the crowns of infested and noninfested trees. Temperatures were generally higher on the east side during the morning hours, equalized during midday, and then became higher on the west side in the afternoon (fig. 1). Differences between the east and west sides were slightly greater during the morning than in the afternoon.

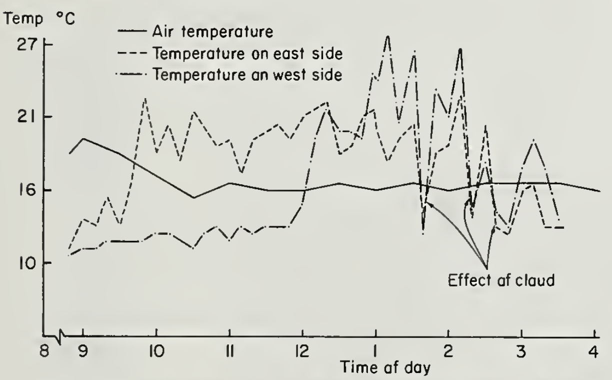

Figure 1.—Needle temperatures on east and west sides of an infested spruce on a day when significant temperature differences developed.

Weather conditions conducive to development of significant temperature differences between infested and noninfested trees were not precisely identified. Differences were greatest on days that were clear and windless during the morning and then became sparsely cloudy with estimated 8-16 km/h winds during early afternoon. Air temperatures and relative humidities at crown level ranged from 15°-17°C and 35-40%, respectively, during the midday hours. Between 6 and 10 a.m. on these days, crown level temperatures were approximately 2.8° warmer than during midday. Such days were generally proceeded by 3 or more days without precipitation. Temperatures and relative humidities on these preceding days were of similar magnitude, but cloudiness and wind varied more.

The "typical" weather conditions in the spruce-fir country partially accounted for the paucity of days with significant differences. Completely clear and windless days developed less than 15 percent of the time in June, July, and August. Frequently, either winds became strong and steady or gusty and cloud cover increased in the afternoons so that temperature differences developing during the morning hours did not continue in the afternoons. When the cloud cover built to a general overcast, needle temperatures of infested and noninfested trees became essentially identical (1° range). During these periods, needle temperatures were about 3° below the air temperature at crown level. This effect was common in the study area, and was the primary reason for so few complete days of temperature recordings with substantial differences between morning and afternoon.

The needle temperatures of the subalpine fir were higher and lower than the spruce, but not consistently either way.

Considering the temperature differences between and within infested and noninfested spruce, thermal imagery alone would not consistently detect infested spruce either before or after visual symptoms develop. Temperatures were not significantly different before visual symptoms developed and postvisual differences were sporadic. Thermal imagery would also be compounded by the development of significant east-west needle temperature differences in both infested and noninfested tree. The "typical" weather conditions in the spruce-fir forests—cloud buildup at midday and throughout the afternoon on the majority of days—also prevents temperature differences from originating.

New Growth

Branches of the infested sample trees developed new growth in the summer following the summer of beetle attack (for example, attacked in 1972, new growth in 1973). The length of the new terminal shoots ranged from 1.25 to 3 cm (averaging about 2 cm), slightly less for lateral shoots. New growth was more noticeable in the lower crown; it was sparse to nonexistent in the extreme upper crown. Other infested trees in the area also put on new growth. New growth on infested spruce trees approximately one year after attack is detrimental to possible aerial detection of infested trees because the new growth partially camouflages the desiccating needles.

Needle Fall

Needles on infested trees fell the summer of attack and the subsequent two summers. The older needles, furthest from the branch tips, fell the first summer (1972). These needles would normally drop in the fall, however, regardless of whether the tree was attacked or not, and therefore might not be influenced by the beetle attacks. Older needles also fell from September 1972 to September 1973, so that by September of the second year (1973) about 30-35% of the needles had fallen. These needles falling roughly

1 to 1.25 years after attack would also be needles normally dropping during this particular year. Since 3-4 yr old needles are drier than 1 yr old needles (Gary 1971), the additional moisture stress caused by the blue staining fungus associated with the spruce beetle probably desiccates these older needles faster than normal, and they fall sooner.

Most of the remaining 65-70% of the needles were still attached at the beginning of the third summer (June 1974) although their color varied from green to yellowish green. From June 1 to July 15, 1974, clusters of needles fell from various branch positions except for the tips or new growth of 1973. Between July 15 and July 29, 1974, strong winds accompanying one inch of rain stripped all the needles on one tree and all needles except the 1973 new growth on the other two infested trees. Only about 5 percent of the needles remained. Surrounding infested trees were similarly stripped during the same period. Just prior to the storm, needles were dry and brittle and dropped off the branch at the slightest touch. By August 22, 1974 less than 1 percent of the needles remained on the infested trees, essentially all in the lower half of the crown. The residual needles were dry and fell readily. The time of falling of these residual needles (remaining 70%) may be quite variable. If the hot dry days which accentuate the drying of needles should occur in early June, then most of the needles might be gone by mid-June. Eventually though, a storm with substantial rain and winds will strip the remaining needles from the trees and defoliation will be essentially complete 2 yrs after beetle attack.

The pattern of needle fall differs from Massey and Wygant's 1954 report which concludes that the needles on infested spruce fall after about one year. They indicate that needles may remain green until the fall of the second year, however, which would be the equivalent of the fall of 1973 in this study. A low density of beetle attacks at breast height (average of 4 per 900 cm^2 in this study versus 6.6 from Knight (1960)) and the incompleteness of the blue stain suggest that, had these factors been greater, needles may have desiccated faster and thus fallen sooner. Perhaps this observed pattern is an exception, but it seems more plausible and better documented than past reports.

Foliage Discoloration

The pattern of foliage discoloration (fading) is different in infested spruce than in infested pine because the pattern of needle dying is different. Since not all spruce needles die at the same time, or at least do not substantially desiccate at the same rate, the crown does not discolor evenly. Clusters of needles die and discolor so that the overall crown apperance is a mottled green-yellow green. The dead needles do not remain on the tree but fall during storms. The constant removal of the yellowish-green needles from the crown leaves it predominantly green but foliage is less dense and the exposed branches contribute a gray cast. This appearance predominated in the summer following attack (roughly 1 yr after attack). During the second summer, most of the remaining needles discolor so that the crown appears more uniformly yellowish green and gray. The color pattern is then more similar to faded infested pines. Eventually a storm removes the remaining needles, leaving the tree a gray skeleton.

Since aerial observers commonly look for discolored spruce as an indication of beetle infestation, their best chance of detecting such trees will be in May-June. Later observations could be worthwhile if no storms have developed. Any discolored trees found during such flights were probably attacked two years prior and will have beetles emerging about the same time as the detection flight.

Aerial detection of infested spruce is difficult because new growth on infested trees partially camouflages them and the needles do not discolor simultaneously nor remain on the tree for long periods after discoloring.

Literature Cited

Denny, C. H., E. L. Morrison, Jr., C. D. Worthman, and D. D. Lucht.
1971. Automated processing of forest imagery. *In* Proc. of 2d ARETS Symp. Univ. Ariz., Tucson. p. 111-117.

Gary, H. L.
1971. Seasonal and diurnal changes in moisture contents and water deficits of Engelmann spruce needles. Bot. Gaz. 132(4):327-332.

Heller, R. C.. R. C. Aldrich, W. F. McCambridge, F. P. Weber, and S. L. Wert.
1968. The use of multispectral sensing techniques to detect ponderosa pine trees under stress from insect or pathogenic organisms. Ann. Prog. Rep., For. Remote Sensing Lab. for Nat. Resour. Prog., NASA, 45 p. [In cooperation with the Pac. Southwest For. and Range Exp. Stn.]

Knight, F. B.
1960. Measurement of Engelmann spruce beetle populations. Ecology 41:249-252.

Massey, C. L., and N. D. Wygant.
1954. Biology and control of the Engelmann spruce beetle in Colorado. U.S. Dep. Agric., Circ. 944. 35 p.

Weber, F. P.
1969. Remote sensing implications of water deficit and energy relationships for ponderosa pine attacked by bark beetles and associated disease organisms. Ph.D. Diss. Univ. Mich., Ann Arbor, 114 p.